Effects Of Langmuir Circulations On The Plankton

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LONG-TERM GOAL

My long term goal is to contribute to our understanding and prediction of the dynamics of marine populations and ocean-atmosphere interactions. Of particular interest to me are the effects of weather, and its climatic variation and long-term change, on the plankton and fish.

OBJECTIVES

My object remains the same as stated previously for this project. I wish to establish whether the plankton is affected by Langmuir Circulations (LCs). LCs are wind and wave induced flows in the mixed layer (ML) and comprised of counter-rotating, helical cells aligned with the wind. They occur widely and frequently. While their surface manifestation is relatively well known, their dynamics and relation to the plankton are less well understood. Of particular interest is the effect of flow on plankton distributions and associated processes, including feeding. The challenge is to measure plankton distributions and processes simultaneous with the physical flow and property distributions.

Specific objectives during the past year have included (a) analysis of the Acoustic Doppler Velocimeter (ADV) data for inference about vertical flow associated with LCs, (b) geostatisical analysis of spatial data, and (c) integration of physical and biological data.

APPROACH

I participated in the second FLIP cruise of the ONR Marine Boundary Layer (MBL) program, approximately 60 miles off Monterey, with marine meteorologists and physical oceanographers. My general approach was to sample the plankton and its environment continuously in the vertical, by profiling between the top and base of the ML with a cycle time about 1-3 minutes, and at a single depth within the ML, at higher frequency. Measurements were made of temperature, salinity, and sigma-*t* (CTD), flow (Acoustic Doppler Velocimeter, ADV), chlorophyll *a* concentration (Chlorophyll Absorption Meter, CHLAM), and zooplankton concentration (plankton pump; collections; Optical Plankton Counter, OPC).

WORK COMPLETED

My annual reports for the past two years summarized progress on this project prior to this year, to which I add the following. We have succeeded in developing correction algorithms for our ADV data, essentially by the objective removal of inconsistent data and its replacement with iterpolated data. This

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has not been a trivial exercise and the result (see below) appears to have been worth the effort. In regard to our second objective, I have collaborated with Dr. Nicolas Bez of the Centre de Geostatistique, Ecole Nationale Superieure des Mines de Paris, France, a geostatician, on the analysis of distributions (time-depth and distance-depth) of physical (especially temperature) and biological (chlorophyll *a* and zooplanktons-sized particles from Optical Plankton Counter data) variables. This also has proved fruitful and has yielded results (below) different than those I originally obtained with less rigorous though more commonly-used analysis of pattern. This collaboration continues and we expect to complete our analyses in December 1999.

RESULTS

As stated in past years, LCs occurred and were quantified by our measurements. Conditions progressed from benign, with a stratified upper ocean, to strong winds and high waves, with well-developed LCs, followed by abatement. Forcing was quantified by estimating LC convergent velocity from wind stress and wave height time series. LCs were manifest in the temperature distribution of our profiler data. In particular, in time-depth domain, sections within LCs showed cool water apparently entrained upward from the base of the mixed layer to the surface. These patterns were persistent for the scale of hours. Temperature at a single depth within well-developed LCs varied in a periodic fashion over a range of the order 0.02 deg C. Such measurements enable us to construct a physical context in which to interpret our biological observations.

Initial analysis of our OPC data showed pattern in the time-depth domain in both stratified (initial) and LC (mid- to late-term) conditions within the experiment. Pattern in stratified conditions showed variation in the vertical and layers in the horizontal. Pattern in LCs showed patchiness in the mixed layer, in both the horizontal and vertical. The challenge has been to establish whether such pattern is real or artifact. While independent verification may not be feasible due to the modest abundance of zooplankters in our collected samples, the internal consistency of our physical (especially temperature, flow) and biological (especially particle concentration) data sets now allows strong inference about the existence of LCs, their physical characteristics, and the distribution of zooplankton-sized particles.

We discussed briefly last year how our desired method of estimating turbulence using our 25-Hz ADV measurements of velocity at a fixed depth within the mixed layer appeared to be subject to artifact. We appear now to have been able to correct those data satisfactorily. The result is vertical velocity data consistent with the temperature distributions. In particular, spurious data have been removed from the 25-Hz ADV data files and replaced with data interpolated using spline functions. The resultant time series of vertical velocity have been low-pass filtered in two directions, forward and reverse, using a period similar to that of our profiling instruments (CTD, OPC) and greater than that of the waves and swell. The results are striking. When the 120-sec, low-pass filtered, vertical velocity (w_{120sec}) time series is superimposed on the time (abscissa) – depth (ordinate) plot of temperature, velocity is clearly seen to vary with temperature (Fig. 1). That is, when ‘tongues’ of deep, cool water penetrate from the top of the thermocline towards the surface within the mixed layer, w_{120sec} is positive upwards, and vice versa. In essence, as hoped and planned, we appear to have successfully measure the residual vertical velocity due to LCs amidst the much greater velocity variation due to surface gravity waves and swell. This, I believe, may be the first time in which LC residual vertical velocity has been measured acoustically. Importantly, it had been done in the open ocean with concurrent biological measurements.

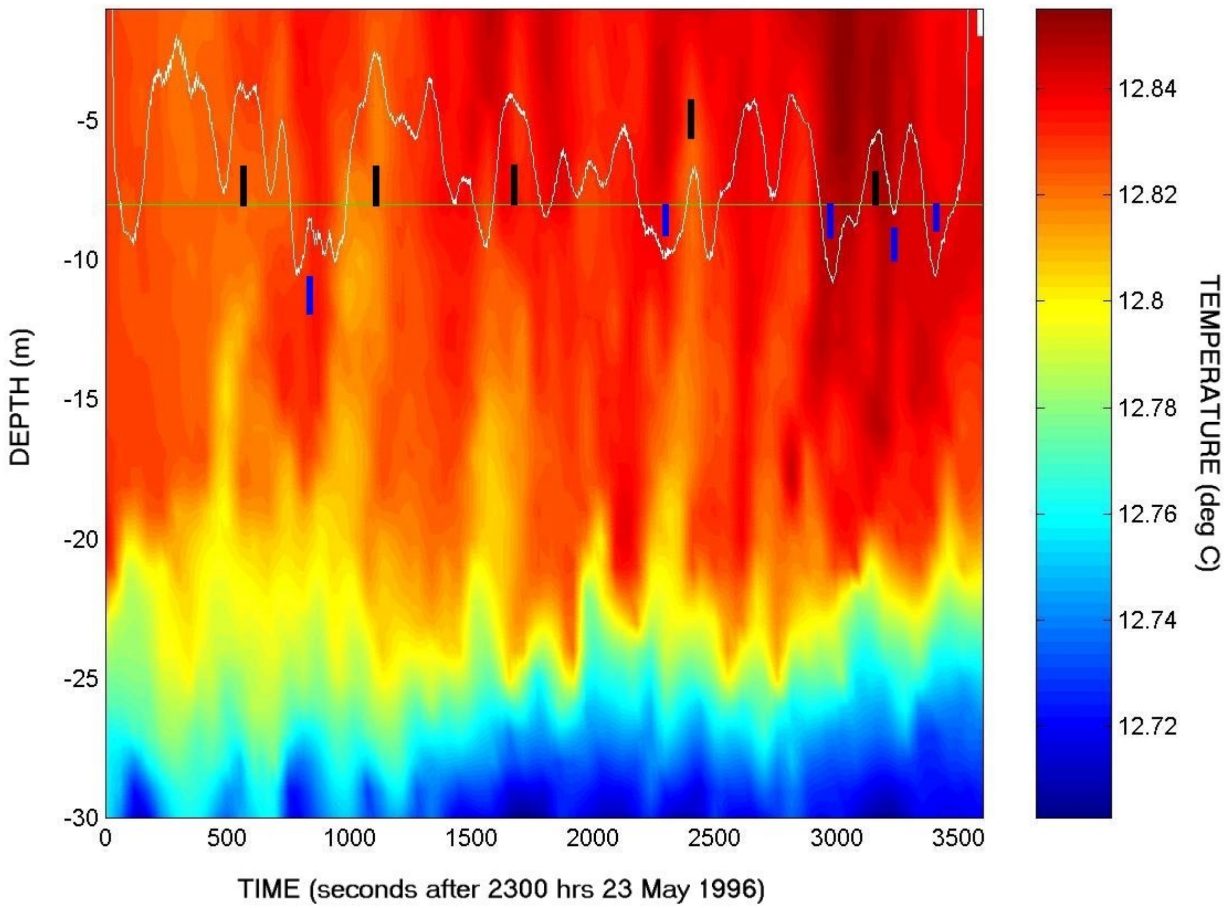

Fig. 1. Low-pass filtered, vertical velocity (w_{120sec}) overlaid on time-depth plot of temperature. Date and time of sampling was one of intense forcing of Langmuir circulations. Colored background shows derived time-depth distribution of temperature from profiling CTD. Only downcast data are used, ca. one cast every 90 seconds. Note tongues of cool, upper thermocline water being wafted into mixed layer. Temperature differential in mixed layer is ca. 0.02 deg C. Note also downward penetrations of warm, surface water. Green horizontal line is nomimal depth of Acoustic Doppler Velocimeter (ADV), 8 m. Yellow line shows vertical velocity from ADV (25 Hz) after low-pass (120 sec) forward and reverse filtering. Absolute scale is not provided, although direction is correct. Initial and final 120 sec of w_{120sec} time series should be disregarded. Variation in w_{120sec} is consistent with that of temperature at the sampled depth . Black bars are subjectively noted times of upward flow and cooling and blue of downward flow and warming .

The other main area of work in the past year has been the analysis of pattern in our data using geostatistics. Dr. Bez is expert in the use of variograms in the analysis of spatial pattern. Thus far, we have found (a) that variograms are appropriate to describe pattern in the profiler data (time-depth and distance-depth); (b) as expected, significant pattern exists for temperature in LCs in the horizontal but not along profiles in the vertical, within the mixed layer; (c) fixed CTD and profiling CTD yield consistent time series; (d) significant pattern exists in LCs in the vertical but not the horizontal for zooplankton-sized particles sensed by the OPC; (e) no structure (pattern) exists in LCs in the horizontal for zooplankton collected with the plankton pump. We will continue with these and other (e.g. flow) analyses in December 1999, with our intent being to complete them and draft a manuscript.

IMPACT/APPLICATIONS

The means by which we have viewed the plankton and its physical environment in this study is novel and appropriate for future investigations. Our ability to measure flow acoustically simultaneous with property distributions may prove valuable to others. The patterns we have observed in the zooplankton during Langmuir circulations have not been seen previously. If accurate, these distributions are more heterogeneous than expected. This has implications for our understanding of pattern in acoustic backscatter, processes such as growth and mortality of the plankton, and the effects of the plankton on the biogeochemistry of the upper ocean. Most importantly, biological structure exists in the presence of strong wind and surface wave forcing.

TRANSITIONS

Our profiling instruments and software have been used in an ONR-funded study of a deep aggregation of copepods in the Santa Barbara Basin (with Kenric Osgood, now at NOAA), now finished. My use of the OPC in this work has led to its modification for internal recording and inclusion of a time-of-flight flow sensor. This modified, *in situ* OPC is now in routine use in the California Cooperative Fisheries Investigations (CalCOFI) and provides data on the depth distribution of the zooplankton to complement the standard, depth-integrated estimates of zooplankton abundance from bongo net deployments. This is proving to be a significant enhancement to the already valuable CalCOFI time series. An ancillary development has been the use of the laboratory OPC for the analysis of the size distribution of historical CalCOFI samples of zooplankton (work of M.M. Mullin funded by Sea Grant).

Software created for use in this project, using LabVIEW in real-time to acquire, archive, and display data, has proven useful in other endeavors. In particular, it has been used with an instrument we (Dr. Peter Ornter, AOML, and I) developed, the Continuous, Underway Fish Egg Sampler (CUFES) for use with a GPS, CT-sensor (conductivity, temperature), fluorometer (Chl *a*), and flowmeter integrated in CUFES, enabling their real-time analysis and use at sea for adaptive sampling. This project, now funded by Sea Grant for three additional years, is now in the phase of automation by use of machine vision.

RELATED PROJECTS

Our ONR-funded investigation of *Calanus pacificus* in the Santa Barbara Basin is now finished and the results published (Osgood and Checkley 1997 a,b). Catherine Johnson, a fourth-year SIO graduate student has developed dissertation research based, in part, on our results. In particular, she is investigating the induction and significance of diapause by *C. pacificus* off Southern California. She has been funded to date by a DOD fellowship. We were recently awarded a two-year ONR contract largely for the completion of her disseration research which, to reiterate, builds upon the results of our prior ONR-funded work with the OPC.

Other, related projects include the investigations have included (a) turbulence with Tom Osborn (Johns Hopkins), (b) pattern with Nicolas Bez (Ecole des Mines), and (c) acoustic backscatter with Rob Pinkel and Jerry Smith (SIO).

PUBLICATIONS

Osgood, K.E., and D.M. Checkley, Jr. 1996. Observations of a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Limnol. & Oceanogr., 42:997-1001.

Osgood, K.E., and D.M. Checkley, Jr. 1997. Seasonal variations in a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Mar. Ecol. Prog. Ser., 148:59-69.